

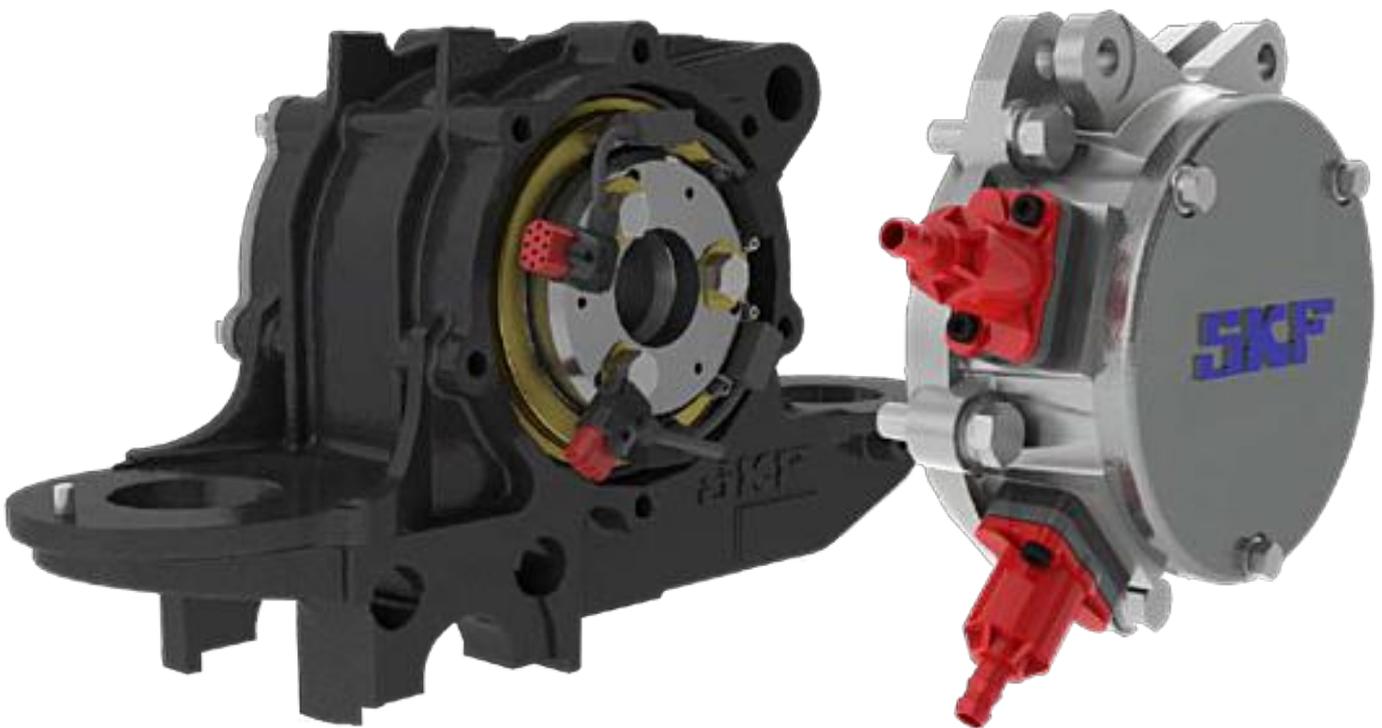
SKF Axletronic sensors

Extract from the Railway technical handbook,
volume 1, chapter 7, page 136 to 151



7 AXLETRONIC sensors

Railway sensors	137
Sensor capabilities	139
Applications	151



AXLETRONIC sensors

Railway vehicles are equipped with several sensors installed in axleboxes to detect and monitor operational parameters such as speed, temperature, and vibration that provide input for several control systems, including brake and condition monitoring systems.

Railway sensors

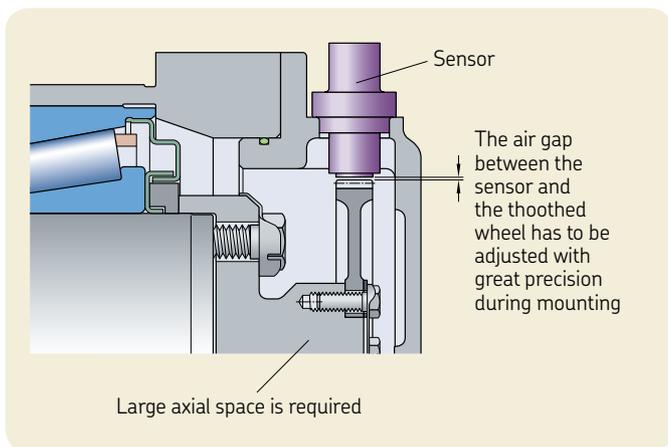
The SKF Axletronic railway sensor solution is a flexible platform for railway vehicles that can be installed in axlebox bearing units or front covers. These axlebox bearing units, or axlebox front covers, provide several options to detect speed and operational parameters for automatic train protection (ATP), automatic train control (ATC), juridical recording units (JRU) – commonly called “black box” – brake control and condition monitoring systems.

One of the first applications was monitoring the speed for wheel slide protection (WSP) in order to avoid skidding and locking during braking. Previous designs were based mainly on inductive and optical speed sensors mounted onto the axlebox cover. This arrangement requires more space and should be considered when the railway gauge/profile cannot accommodate additional space. For this design, a toothed wheel is usually located at the end of the axle and has to be mounted separately. During installation, the air gap between the toothed wheel and the measuring equipment mounted on the housing has to be adjusted with great precision. Usually,

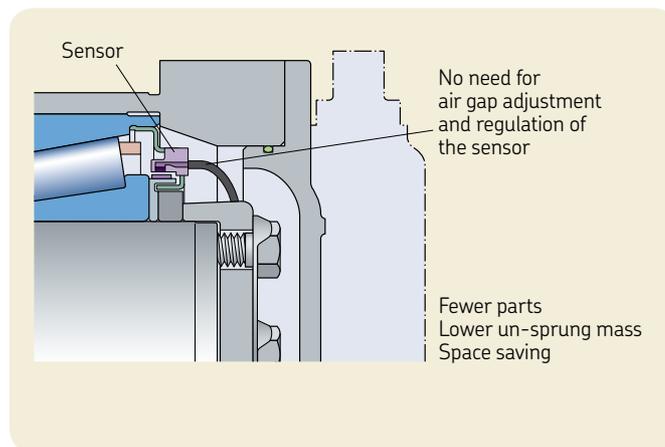
such solutions tend to have a rather large number of components. In railway applications, as in many other fields, the trends are to reduce both the number of components and suppliers as well as the space occupied and un-sprung mass. Considering that un-sprung mass influences the dynamic load between wheel and rail as well as the wear of both, which in turn affects passenger comfort during travelling, vehicle manufacturers and railway operators are increasingly interested in compact solutions [27, 28, 29].

An SKF Axletronic sensor solution can be easily installed in both new and existing vehicles. There are two SKF Axletronic configurations available to the railway industry, depending on where the sensor should be located:

- sensor systems installed onto the bearing seal as an integral part of the axlebox bearing unit
- sensor systems installed within the axlebox front cover that do not interfere with the bearing unit



Example of a conventional sensor mounted onto the axlebox and a toothed wheel located at the end of the axle



Example of an SKF Axletronic sensor integrated in an axlebox bearing unit

Bearing unit sensors

The pre-lubricated and sealed bearing units can be based on either tapered or cylindrical roller bearing unit designs, with integrated sensors. The design of the bearing unit's seals accommodates the sensors. If these sensors are for measuring speed, the encoder or impulse wheel also forms a part of the sealing system. The system is mechanically fitted on the journal after the bearing unit has been mounted.

For compact tapered roller bearing units, the metal ring of the bearing seal is used as an impulse wheel. The special shape is produced by laser cutting.

For cylindrical and tapered roller bearing units, the impulse wheel is produced by vulcanizing a metal ring with rubber coating containing magnetic particles. The metal ring is part of the sealing system. This special design is compatible with oils and greases and can withstand extreme temperatures. Its compact design requires less space in the axlebox than conventional designs and has fewer components.

There are retrofit kits available for easy upgrades of bearing units during maintenance. These kits comprise:

- a new outer seal
- a magnetic impulse wheel
- an intermediate front cover
- an external cable
- a sensor

Front cover sensors

SKF Axletronic sensors are also designed for integration within the axlebox front cover. This solution is especially valuable for upgrading existing rolling stock as well as encouraging original equipment manufacturers to add the wheel speed function without implementing major design changes. The sensor is placed within the axlebox front cover and can be used with any type axlebox bearing.

This solution is supplied as a kit, with no need to fit the sensor onto the front cover. It can be used for new and existing trains.

Main components are:

- a toothed end-cap
- an intermediate front cover
- an external cable
- a sensor

The package comprises the SKF Axletronic sensor and its external cable with customized connectors that are mounted on the vehicle's body. This package is a ready-to-mount sensor solution that can be used for ATP, ATC, WSP, temperature or condition monitoring systems.

SKF Axletronic benefits

- compact design with fewer components, which saves space and mass
- enables the combination of sensors with mounted earth brush on one axlebox
- possible to integrate several speed sensors using the same impulse ring
- tailor-made sensor configuration based on individual customer specifications
- easy mounting and signal checking
- no adjustment of air gap and alignment
- better and longer performance
- no maintenance needed
- lower life cycle cost

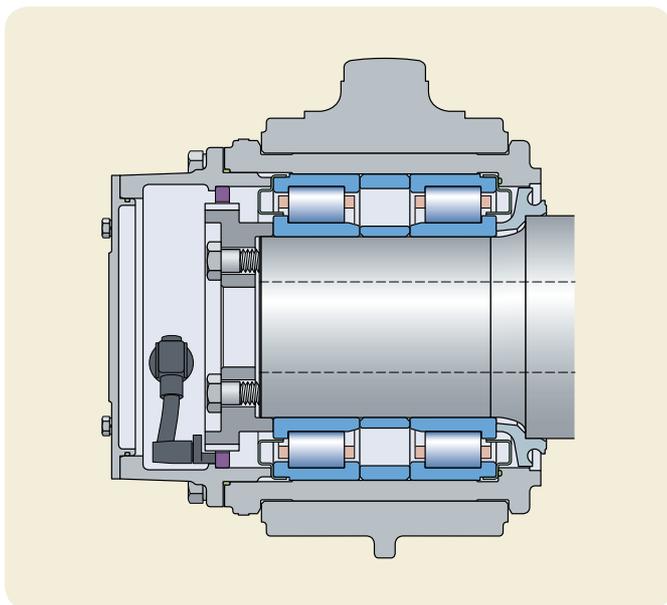
The first field tests of SKF Axletronic sensors were conducted in 1990. Soon after that, this design principle became the standard for main manufacturers of high-speed trains, locomotives, multiple units and mass transit vehicles.

Sensor capabilities

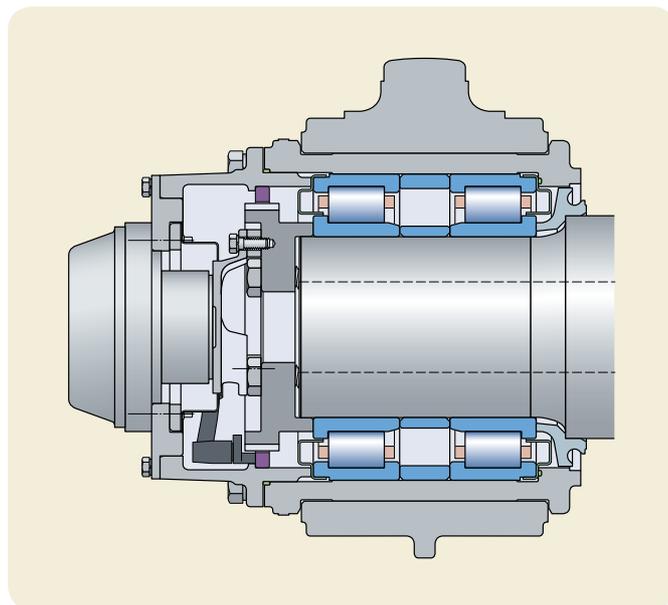
The SKF Axletronic sensor is a very versatile sub-system for railway application that supplies a greater range of signals than conventional axlebox sensor solutions. In most applications, measuring of the rotational speed is needed, either to be used as stand alone signal for several applications, or to manage data evaluation in combination with direction of movement for odometry systems (distance measurement). The SKF Axletronic sensors detect vertical and/or lateral acceleration signals, which are used for bogie condition monitoring systems. There are applications where only bearing temperatures are detected. However, these data can be used in combination with other parameters, such as bogie condition monitoring.

To manage the parameter requirements, there are several SKF Axletronic sensor configurations available with one or more channels, distributed on the circumference of the bearing unit seal or within the axlebox intermediate front cover.

SKF Axletronic sensor integrated into the axlebox front cover



SKF Axletronic sensor integrated into the axlebox front cover with earth return



Sensor capabilities

Parameter	Applications
Rotational speed	Wheel Slide Protection (WSP) Tachograph Juridical Recording Unit (JRU) Drive Information System (DIS) Traction control Motion detection Bogie condition monitoring Passenger Information System (PIS) Watt-hour meter
Direction of rotation	Legacy Automatic Train Protection (ATP) Automatic Train Operation (ATO)
Odometric	Automatic Train Control (ATC) European Train Control System (ETCS) Communication Based Train Control (CBTC)
Odometer (distance measurement)	European Train Control System (ETCS)
Bearing temperature	Bearing damage detection
Vertical vibration	Bearing damage detection
Lateral vibration	Bogie condition monitoring – wheel condition Bogie condition monitoring – bogie stability

Rotational speed detection

The first SKF Axletronic sensors were designed for rotational speed detection, including movement detection. This signal is used for wheel slide protection (WSP) to avoid skidding and locking during braking, especially for high-speed operation of railway vehicles. Another typical application are tachograph systems. These safety-critical systems use the SKF Axletronic sensor for speed signal input, which is used in electronic railway units.

The SKF Axletronic speed sensor is based on a non-contact measurement of the magnetic flux and number of pulses per revolution. The number of pulses per revolution, together with the wheel diameter, establishes the resolution arc. This is the angular section of the magnetic impulse ring covered by each pulse. The distance covered by the wheel is a function of two subsequent pulses. There are two different configurations:

- active full bridge transducer based on **current transition** with a square digital transition waveform
- active full bridge transducer based on **voltage transition** with a square digital transition waveform

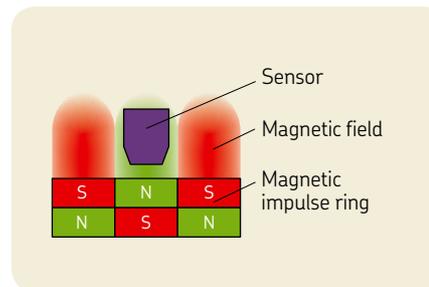
Today, rotational speed is requested as additional data for processing several other applications, such as Drive Information System (DIS), Juridical Recording Unit (JRU), motion detection, Passenger Information System (PIS) and Watt-hour meter.

The output signal of the SKF Axletronic transducer has a sine wave form with

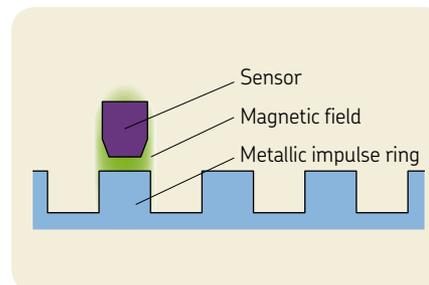
constant amplitude and a frequency proportional to the rotational axle speed. This basic signal can be treated to obtain the square wave form required by the electronic system.

Depending on the customer's electronic unit specification, the following configurations can be supplied:

- Voltage PNP
- Voltage NPN
- Voltage Push-Pull
- Current



Magnetic flux variation principle – magnetic impulse ring

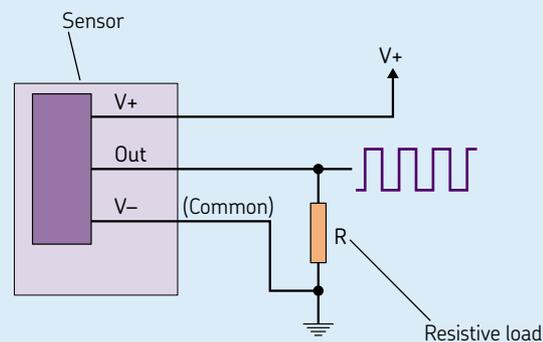


Magnetic flux variation principle – metallic impulse ring

Voltage PNP

This bipolar transistor consists of a layer of N-doped semiconductor between two layers of P-doped material. The PNP output is an open collector transistor. The resistive load is connected between output and common. The voltage PNP configuration is also known as current sourcing.

Voltage PNP configuration

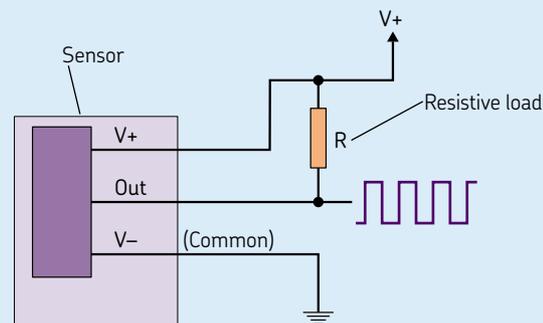


Voltage NPN

NPN is the most common bipolar transistor and consists of a layer of P-doped semiconductor between two layers of N-doped material.

The NPN output is also an open collector transistor. The resistive load is connected between positive voltage V+ and output. The voltage NPN configuration is also known as current sinking.

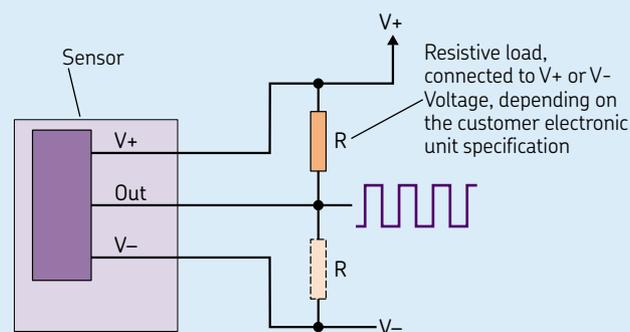
Voltage NPN configuration



Voltage Push-Pull

This output is implemented with a pair of transistors: one in sink mode and the other in source mode. The signal is taken from the midpoint between two transistors, which function as one NPN and one PNP. The resistive voltage could be referred to both positive voltage V+ or negative voltage V-, depending on the electronic unit specification.

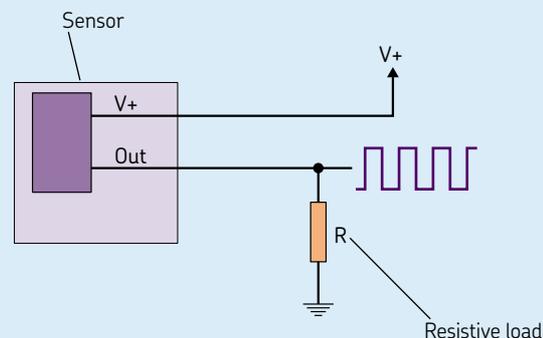
Voltage Push-Pull configuration



Current

This is an electronic circuit in which the output switches between two current values. When a resistive load is connected to the output, the two levels can be read as voltage variation across the resistor. This signal is normally sent to an optocoupler in order to realize the interface with the electronic unit power supply.

Current configuration



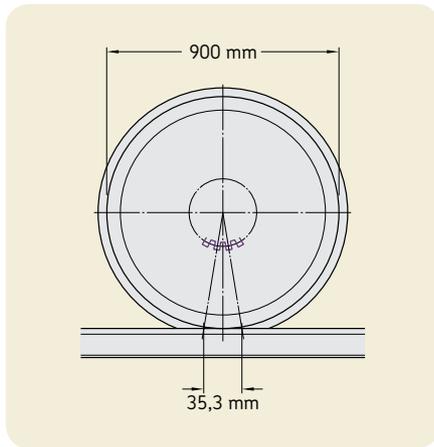
Impulse wheel designs

There are three different impulse wheel designs used for different applications:

- impulse wheel with vulcanized rubber containing ferromagnetic metal particles; integrated into the bearing unit seal design; used for axlebox bearing units
- metallic impulse wheel with slots; integrated into the bearing unit seal design; used for compact axlebox bearing units
- metallic impulse wheel with slots; mounted onto the wheelset axle end; used for retrofitting existing axleboxes with SKF Axletronic systems

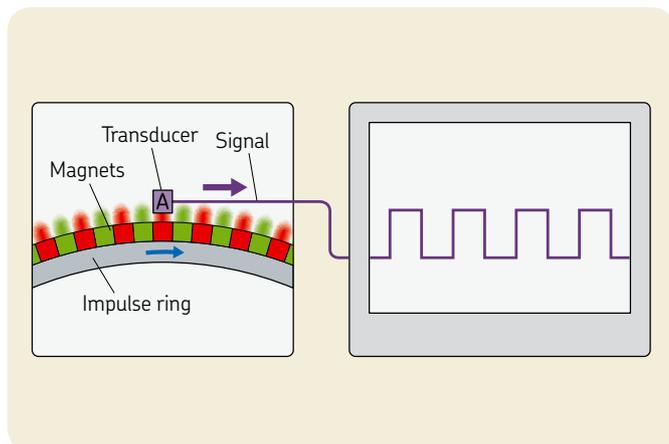
Direction of movement

Some systems require information about the direction of rotation. In this case, double speed signals, shifted 90°, are needed. The detection of the direction of movement is required to determine the train's positioning for train control and management systems. Typical applications are Communication Based Train Control (CBTC), Automatic Train Protection (ATP) and the European Train Control System (ETCS). Double speed signals are mainly required for the odometry of all traffic management systems to observe the appropriate speeds and avoid collisions with other trains.

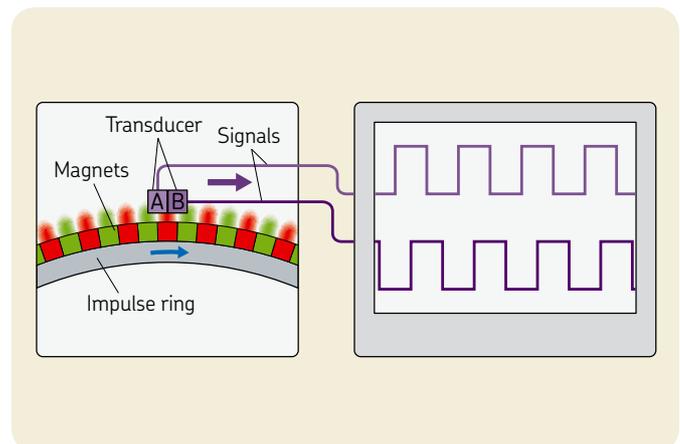


Typical sensor resolution example with 80 pulse impulse wheel

Rotational speed "Single head" SKF Axletronic sensor with one channel



Rotational speed "Single head" SKF Axletronic sensor with two channels



Sensors for automatic train control systems

For automatic train control systems (ATC), a package of data is needed and multiple independent parameter measurements are required to achieve redundancy for security reasons. One of the SKF Axletronic sensor design advantages is the ability to apply more sensors, distributed on the circumference of the bearing unit seal or on the intermediate front cover of the axlebox, to measure several parameters.

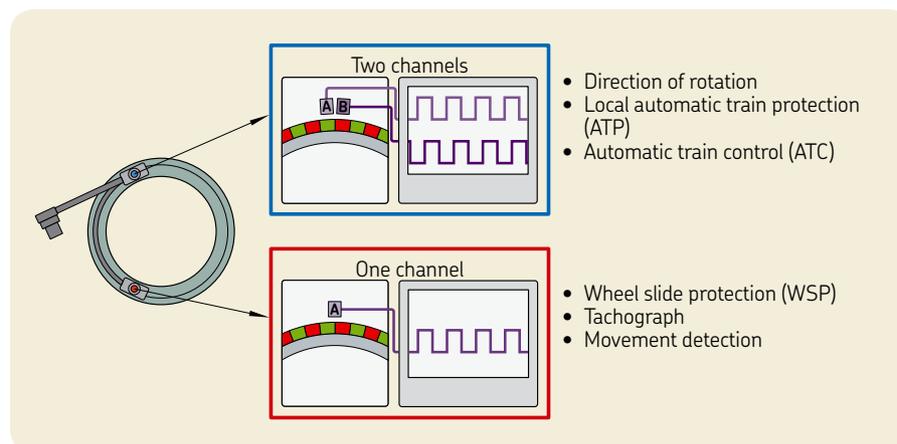


“Single head” SKF Axletronic speed sensor for wheel slide protection (WSP), tachograph and movement control



“Double head” SKF Axletronic speed sensor for automatic train control (ATC) and ETCS applications

7



“Double head” SKF Axletronic speed sensors with a two-channel design and a one-channel design

Odometer sensors for ETCS

There are some 20 different signalling and speed control systems installed throughout Europe. These systems have been historically developed on a national basis, without considering common international technical and operational standards. This results in very high costs for equipment investment and maintenance, as well as an increased risk of breakdown and the increased challenges of complex operation, including driver training and workload. Having several different systems on board and the need for tailor-made designs for each specific route increase the cost. The driver's cab has to be equipped with different signalling systems plus a dedicated screen for operation on specific lines. These technical barriers have been a bottleneck for international rail interoperability.

Further train control systems are used in China, where the Chinese train control system is based on the latest European technology and adapted for the requirements of Chinese railways.

The European Rail Traffic Management System

Traffic management systems make sure that trains operate safely and efficiently on the correct tracks, observe the speed limits and avoid collisions with other trains.

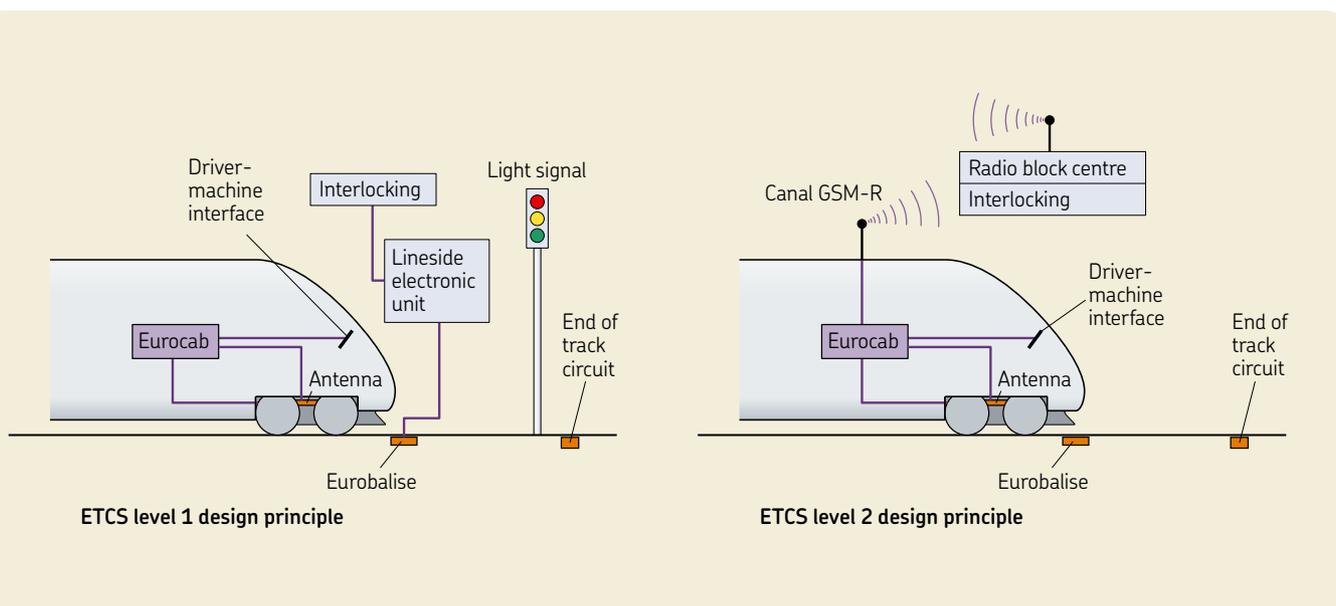
The European Rail Traffic Management System (ERTMS) features two basic functions: communication and control.

The communications function, GSM-R, is based on the GSM standard but uses different frequencies and offers certain advanced functions. It is a radio system used to exchange voice and data information between trackside and on-board.

The European Train Control System (ETCS) is basically a train-based computer, the Eurocab, which compares the speed of the train as transmitted from the track to the maximum permitted speed and slows the train down automatically if the speed is exceeded. With ETCS, a track-mounted device called Eurobalise sends information to the train, enabling it to continuously calculate its maximum permitted speed. On lines where there is trackside signalling (lights and traffic signs enabling the driver to know the permitted speed), this information can be forwarded by standard beacons (light signals) located along the track and connected to the Eurobalises. This is ETCS level 1.

For ETCS level 2, information can also be forwarded by radio (GSM-R), and trackside signals are no longer required. This enables substantial savings in investment and in maintenance. The position of trains is still detected by trackside systems.

For ETCS level 3, the train itself sends its rear-end location, making it possible to



optimize line capacity and further reduce the trackside equipment. For all levels of ETCS, the train-based Eurocab computer compares the train's speed to the maximum permitted speed and automatically slows the train down when required.

ETCS will be compulsory in Europe for any new installation or renewal of signalling for a number of rail corridors. In addition to ETCS requirements, the SKF Axletronic sensors also meet the requirements of other national automatic train protection systems such as:

- German LZB (Linienzugbeeinflussung)
- Italian SCMT (Sistema controllo movimentazione treno)
- Spanish ASFAD (Aviso de Señales y Frenado Automatico Digital)

Global applications

Because of the SKF Axletronic sensor design principle, it is possible to apply several sensors for different electronic systems distributed on the circumference of the bearing unit seal or axlebox front cover. The international rail transport industry is implementing a new common system. Similar efforts have already started in other countries outside Europe, including China, India, Japan, Korea and Russia.

SKF Axletronic odometers

An increasing number of new railway vehicles use odometers, which indicate the distance travelled like a mileage counter. These are also used for train positioning as well as to monitor mileage. Odometers are also used for ETCS systems to identify the vehicle position on the track. New and existing vehicles could be easily upgraded with SKF Axletronic odometers.

Technical features

The SKF solution can provide an independent redundancy system that meets the safety requirements of several specifications through a number of independent odometer sensor configurations. Another benefit of the use of this integrated odometer is that the original axle can be used without any design changes.

- The SKF Axletronic odometer is a flexible, modular solution that can be tailored to individual customer's requirements. The installation is a plug-and-play solution, requiring no adjustment or calibration.
- The non-contact design of the SKF Axletronic odometer means that its components are not subject to wear caused by contact. A functional signal inspection can be performed without moving the train or the wheelset. No further maintenance is needed.

3D model of an axlebox equipped with an AXLETRONIC odometer unit



- The main advantage of the SKF Axletronic design is the “free axle end.” This is in contrast to conventional odometers that are designed to be installed at the end of the front cover with mechanical connection to the rotating wheelset, through an additional small shaft that must be supported by bearing and sealing components. These designs need more space and block the interface for earth return devices, which are compulsory for most rolling stock axleboxes to avoid current flow through the bearing.

SKF Axletronic odometer configurations

Two SKF Axletronic odometer configurations are available for railway applications, depending on where the sensor is located:

- sensors are installed onto the bearing seal as an integral part of the axlebox bearing unit
- sensors are installed onto the axlebox front cover that do not interfere with the axlebox bearing unit

Bearing unit installation

In this case, the pre-lubricated and sealed bearing units can be based on either tapered or cylindrical roller bearing unit designs with integrated sensors. The bearing units' seals accommodate the odometer sensors. This is a smart and easy solution that saves space and components.

SKF Axletronic odometer benefits

- modular solution with plug-and-play installation
- independent and redundant speed signals
- adjustment or calibration not required
- compact design
- maintenance-free
- earth brush can be installed together with the SKF Axletronic sensor
- free axle end for ultrasonic inspection
- retrofit solution for upgrading existing rolling stock
- can be used for any bearing type and manufacturer

There are two different retrofit kits offered for upgrading SKF bearing units:

- for upgrading already sensorized SKF bearing units:
 - speed sensors
 - an external cable
 - an adapter for the front cover
- for upgrading non-sensorized SKF bearing units:
 - speed sensors
 - a new outer seal
 - a magnetic impulse wheel
 - an intermediate front cover
 - an external cable
 - an adapter for the front cover

SKF Axletronic sensor applied in an axlebox front cover in combination with an earth return device
Photo: Siemens



Two independent SKF Axletronic odometer sensors in an axlebox front cover, inside view



Axlebox bearing unit with SKF Axletronic “Quadruple head” sensor systems installed onto the bearing seal as an integral part of the bearing unit

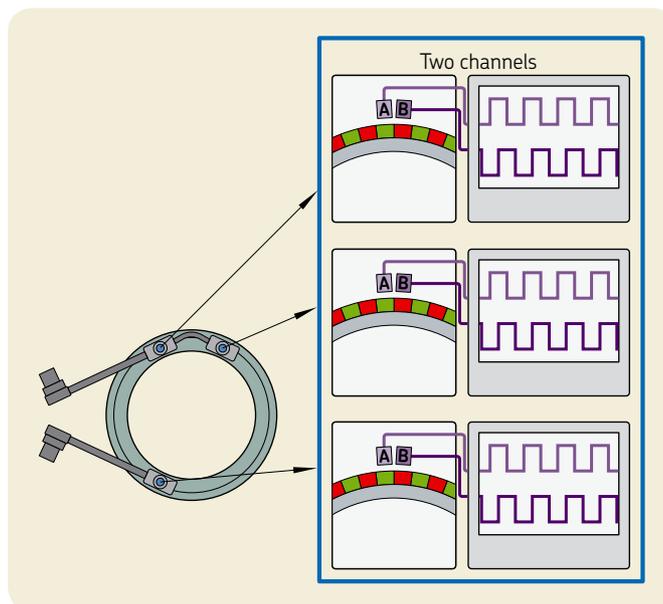


Axlebox front cover installation

In some cases, customers require unmodified bearing units. SKF Axletronic odometers are designed for integration with the axlebox front cover. This solution is especially valuable for upgrading existing rolling stock as well as supporting original equipment manufacturers to add the odometer function without implementing major design changes. The odometer sensor is placed on the axlebox front cover and can be used with any type of axlebox bearing with a sensor mounting plate and a toothed end cap.

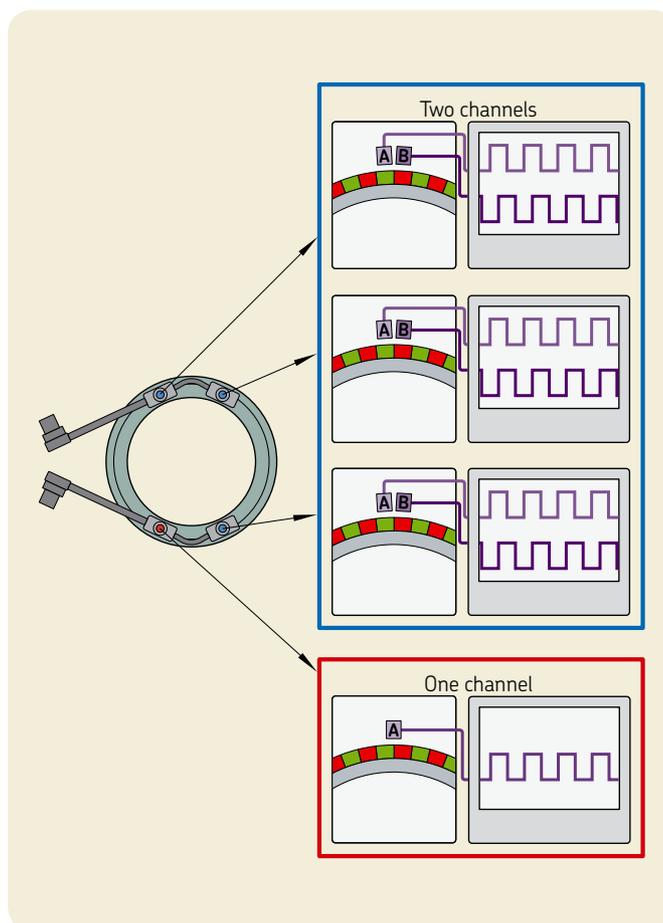
A typical retrofit kit for upgrading axleboxes contains:

- sensors
- a toothed end cap
- an intermediate front cover
- an external cable
- an adapter for the front cover



“Triple head” SKF Axletronic sensor system
with three independent two-channel sensors for ETCS

“Quadruple head” SKF Axletronic sensor system
with three independent two-channel sensors for ETCS and one one-channel sensor for other applications such as wheel slide protection (WSP), tachograph and movement

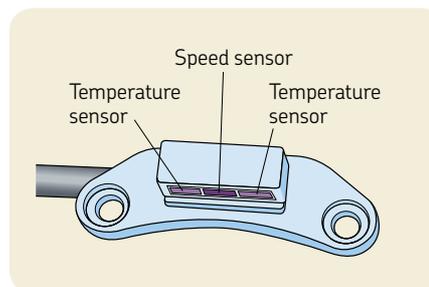


Condition monitoring sensors

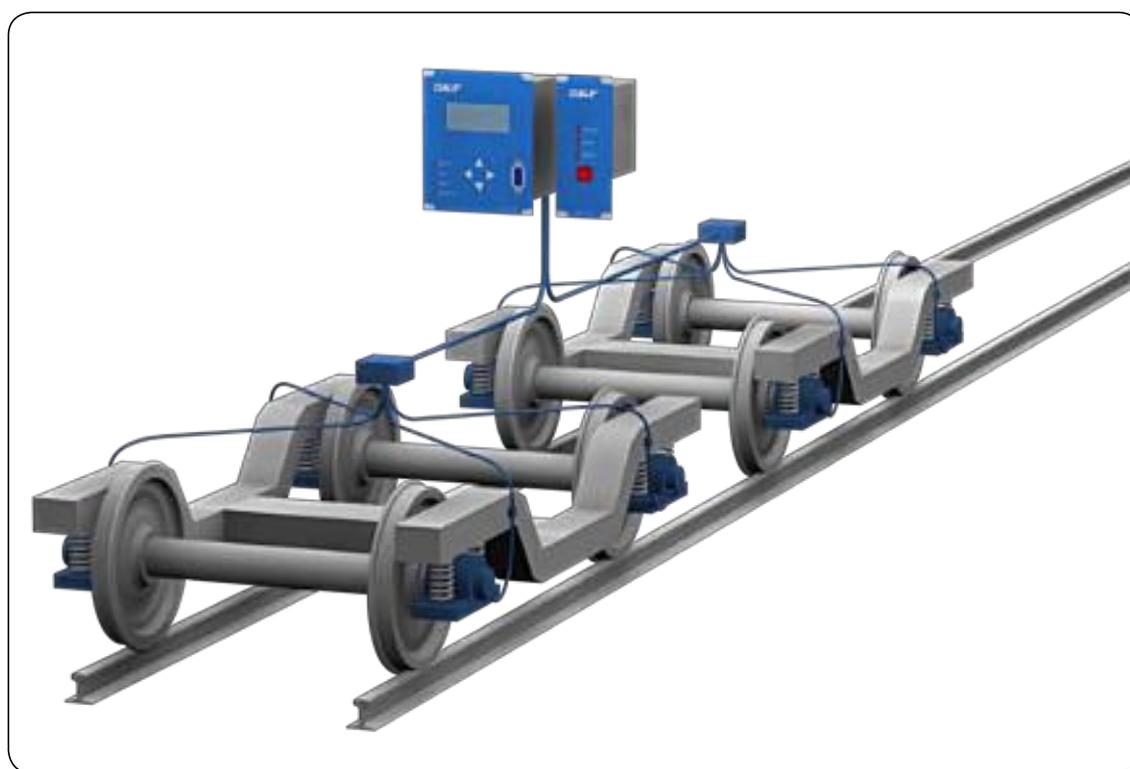
Temperature detection

Axlebox temperature monitoring started decades ago in the railway industry by means of stationary trackside-mounted temperature detection systems. This stationary equipment, also called hot box detectors, is typically installed at certain intervals along the track or at strategic locations, such as ramps in the case of alpine railway lines. The measurement frequency depends on the distance between stationary installations and can take too long to detect all occurring hot running bearing cases. A further disadvantage of track side hot box detection is the indirect measurement of the bearing temperature.

For the first applications of sensorized bearing units, bearing temperature sensors were installed as well as rotational speed sensors for the wheel slip protection system. The main advantage of this installation was the continuous temperature monitoring that can be performed either by on-board monitoring with signals sent to the driver's cab, or by embedding the data into a condition monitoring system. More details on the system's requirements for condition monitoring are mentioned in prEN 15437-2:2010 (→ **chapter 8**).



“Single head” SKF Axletronic sensor system
for detecting the rotational speed and temperature applied for tapered roller bearing units (TBU)



Continuous temperature detection system

The on-board integrated bearing temperature monitoring solution is located entirely on the train. Main features:

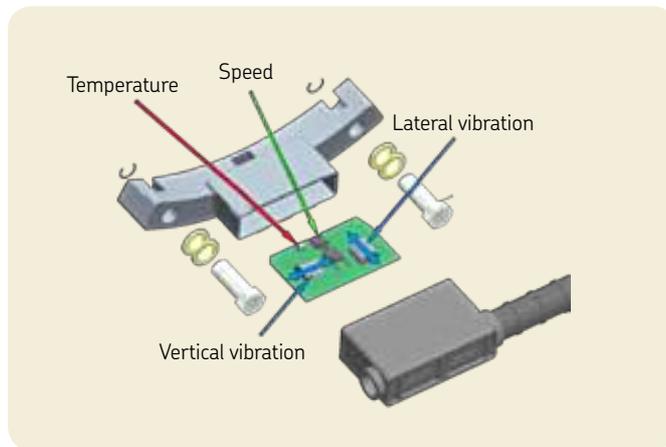
- continuous monitoring of bearing temperature related events
- temperature measurement is performed very close to the load zone of the bearing's outer ring raceway
- the system transmits warning and alarm messages directly to the train driver
- the temperature sensors are fully integrated into the axlebox bearing unit
- the signals are converted in function boxes (one per bogie) to a digital format and transmitted via dedicated bus to the central temperature monitoring unit

Vibration detection

The vibration sensors detect acceleration. Vibration signals measuring in vertical direction are used for bearing damage detection, and wheel/bogie condition monitoring systems. Vibration signals measured in lateral direction refer to the bogie condition monitoring and stability (→ chapter 8).

Multi-functional sensor

Typically, several parameters are detected in combination with vibration detection, such as rotational speed, bearing temperature, etc. The sensors are all integrated into the sensor housing.



SKF Axletronic sensor system detection capabilities

This sensor design is used for compact tapered roller bearing units (CTBU)

Axlebox compact tapered roller bearing unit (CTBU)

equipped with a multi-functional SKF Axletronic sensor system



Performance verification

The sensor and cable performance verification equipment enables the inspection of all connections to make sure they are working properly. This method enables validating the performance without moving the wheelset. SKF offers customized electrical and manual performance verification equipment.



Manual SKF Axletronic sensor tester



SKF Axletronic demo unit

SKF Axletronic sensor general specification

Detection parameter	Sensor configuration	Power supply	Operating temperature
Speed and direction	Voltage PNP Voltage NPN Voltage Push-Pull Current	10 to 30 V DC	-40 to +110 °C
	Temperature	Negative temperature coefficient (NTC) Platinum temperature resistor (PT)	
Thermal diode		12 to 24 V DC	
Vibration	Piezoelectric effect	18 to 28 V DC 2 to 20 mA	

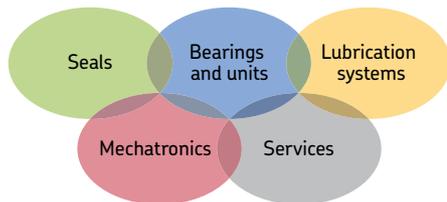
Applications

The first SKF sensorized axlebox bearings were installed in 1990 for field testing and were followed by serial installations in Italy in 1991. Since then, all Italian high-speed trains have been equipped with SKF Axletronic solutions. The Italian Pendolino tilting trains, which are also used by many other European railway operators, are also completely equipped with SKF Axletronic solutions like most of the other Italian locomotives and multiple units.

Other European railway vehicles, such as high-speed trains, locomotives, multiple units and mass transit cars, especially in Austria, Czech Republic, France, Italy, Poland, Portugal, Slovenia, Spain, Switzerland and UK, are equipped with SKF Axletronic solutions.

Additionally, these SKF axlebox sensor solutions are also used outside Europe, in countries such as China, Morocco, Russia, South Africa, Turkey and Venezuela.

Meanwhile, a very large number of applications are equipped with SKF Axletronic sensors and are in service all over the world.



The Power of Knowledge Engineering

Drawing on five areas of competence and application-specific expertise amassed over more than 100 years, SKF brings innovative solutions to OEMs and production facilities in every major industry worldwide. These five competence areas include bearings and units, seals, lubrication systems, mechatronics (combining mechanics and electronics into intelligent systems), and a wide range of services, from 3-D computer modelling to advanced condition monitoring and reliability and asset management systems. A global presence provides SKF customers uniform quality standards and worldwide product availability.

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